Fatty acid content of avocados (*Persea americana* Mill. cv. Hass) in relation to orchard altitude and fruit maturity stage

Contenido de ácidos grasos del aguacate (*Persea americana* Mill. cv. Hass) en relación a la altitud del cultivo y el estado de madurez del fruto

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ABSTRACT

The objective of this research was to study the relationship between the fatty acid content and the altitude of orchards and fruit maturity stage of avocados (*Persea americana* Mill. cv. Hass) at different locations in the department of Antioquia (Colombia). Orchards between 1,340 and 2,420 m a.s.l. were selected and the fatty acid profile and content of the fruits were analyzed. Oleic acid showed the highest percentage for all of the locations and its percentage decreased drastically at lower altitudes, meanwhile the percentage of palmitoleic and linoleic acids increased in these orchards. The oleic/palmitoleic, linoleic/palmitoleic, and oleic/linoleic indexes increased significantly at higher altitudes. Palmitoleic acid increased significantly with the maturity stage (dry matter content) of the avocados for all of the locations. Some fatty acids showed a high linear correlation with the fruit maturity stage, varying the type of acid or index with altitude. The fatty acid content is a variable to consider in future studies for a protected designation of origin (PDO), due to the close relationship observed with the geographical growing area and its importance to human health. More assessments must be taken over the course of years and harvests with more contrasting environments in order to obtain more robust information and feed the model.

Key words: tropical fruit, growing area, monounsaturated fat, origin markers, health, certifications.

RESUMEN

El objetivo de esta investigación fue estudiar la relación entre el perfil y contenido de los ácidos grasos y la altitud de los cultivos y el estado de madurez del fruto de aguacate cv. Hass (*Persea americana* Mill.) en diferentes localidades del departamento de Antioquia (Colombia). Se seleccionaron fincas entre los 1.340 y 2.420 msnm de altitud y se analizó el perfil y contenido de los ácidos grasos en los frutos. El ácido oleico registró el porcentaje más alto para todas las localidades estudiadas y su porcentaje disminuyó drásticamente a bajas altitudes, mientras que los porcentajes de ácido palmitoleico y linoleico aumentaron en estas fincas. Los índices oleico/palmitoleico, linoleico/palmitoleico y oleico/linoleico fueron significativamente superiores a mayor altitud. El ácido palmitoleico aumentó significativamente con la madurez del fruto (contenido de materia seca) para todas las localidades. Algunos ácidos grasos mostraron una alta correlación linear con la madurez del fruto, variando el tipo de ácido o el índice de ácido graso con la altitud. El contenido de ácidos grasos es una variable a considerar en futuros estudios de denominación de origen protegida (DOP), debido a la estrecha relación observada con la localización geográfica y su importancia para la salud humana. Se debe seguir realizando evaluaciones a través de los años, cosechas y en más ambientes contrastantes para obtener una información más robusta, y así alimentar el modelo.

Palabras clave: frutos tropicales, área de producción, grasas monoinsaturadas, marcadores de origen, salud, certificaciones.

Introduction

The avocado growing area of Colombia began to expand in the sixties by replacing native avocados with cv. Hass (*Persea americana* Mill.) because this cultivar had better acceptance in international markets, excellent organoleptic characteristics and higher resistance to the postharvest process. In 2012, the 'Hass' avocado covered 9,000 ha, distributed in the provinces of Antioquia, Tolima, Cauca, Quindio, Caldas, Valle del Cauca and Santander. Antioquia had basically 2,300 ha in the municipalities of El Retiro, La Ceja, Guarne, San Vicente, Rio Negro, Marinilla, Sonson and Abejorral (Mejía, 2012).

In Colombia, avocado crops are found between 1,200 and 2,600 m a.s.l., exhibiting a wide range of adaptation, but the fatty acid profile of this fruit has not yet been studied in terms of agro-climatic zones or altitudinal ranges as a potential marker for geographical origin related to quality and health parameters of fruit for future certifications in

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protected designation of origin (PDO). Today, agriculture practices differentiated by quality are needed, which involve the production of crops in environments that provide conditions that meet the agro-ecological requirements and high quality requirements of plants.

As a climacteric fruit, the avocado does not ripen on the tree, so it must be harvested in the appropriate physiological maturity stage to obtain the edible characteristics of taste and firmness (Gamble *et al*., 2010). It is very hard to visually determine the right maturity stage of 'Hass' avocado at harvest because this fruit does not exhibit any notable external change in its appearance (Kassim *et al*., 2013).

The avocado is an important tropical fruit and a good source of lipophilic phytochemicals, such as monounsaturated fatty acids, carotenoids, vitamin E and sterols, that have been inversely related to cardiovascular diseases. Villa-Rodríguez *et al.* (2011), studying the effect of maturity stage on the fatty acid content in 'Hass' avocados, identified the main fatty acid as oleic acid (about 67-70% of total content). In general, a significant increase in monounsaturated and saturated fatty acids was observed during avocado ripening, while the polyunsaturated fatty acid content decreased.

Yanty *et al.* (2011) compared the characteristics of oils from three Malaysian avocado (*Persea americana*) cultivars with the oils from the Australian avocado Hass variety. As a common characteristic, the oils of both the local cultivars and the Hass variety were found to have oleic acid as the most dominant fatty acid. However, there were differences between them with regard to the proportional distributions of palmitic and linoleic acids.

Donetti and Terry (2014) suggested oleic acid as a potential biochemical marker for distinguishing the fruit origin of imported 'Hass' avocado fruits. The authors found that the oil composition differed according to origin and harvest-time. Chilean fruit had a higher oleic content (57-61%), followed by Spanish (54-60%) and Peruvian (40-47%) fruits. According to Pedreschi *et al.* (2014), linoleic acid is differentially accumulated during the ripening of 'Hass' avocados. This suggests the potential use of the fatty acid content as an origin and health quality marker in avocado fruits for certifications in PDO.

According to Dreher and Davenport (2013), 'Hass' avocado oil consists of 71% monounsaturated fatty acids, 13% polyunsaturated fatty acids and 16% saturated fatty acids, which helps to promote healthy blood lipid profiles and enhance the bioavailability of fat soluble vitamins and phytochemicals. There are eight preliminary clinical studies showing that avocado consumption helps support cardiovascular health (Grant, 1960; Alvizouri-Munoz *et al*., 1992; Colquhoun *et al*., 1992; Lerman-Garber *et al*., 1994; Carranza *et al*., 1995; López-Ledesma *et al*., 1996; Carranza-Madrigal *et al*., 1997; Pieterse *et al*., 2005). Exploratory studies suggest that avocados may support weight management and healthy aging (Unlu *et al*., 2005; Bes-Rastrollo *et al*., 2008; Johnson *et al*., 2010; Rosenblat *et al*., 2011; Sabaté *et al*., 2012).

The aim of this research was to study the relationship between the fatty acid content and the altitude of orchards and fruit maturity stage of 'Hass' avocados at different locations in the department of Antioquia in Colombia as a potential biochemical marker of geographical origin and health quality for use in PDO certifications.

Materials and methods

Plant material

Different 'Hass' avocado orchards located in different regions of Antioquia were selected with altitudes above sea level between 1,340 and 2,420 m a.s.l. (Tab. 1).

On each farm, plots were selected by tree age and homogeneity. Three sectors were identified by slope in the orchards of Entrerrios, Rionegro and Jerico and three trees per sector were randomly selected. From each tree, two homogenous fruits at the same height were taken. For the orchards of Tamesis and Venecia, two sectors were identified, three trees per sector were randomly selected and from each tree, two homogenous fruits at the same height were taken. One

TABLE 1. Orchards selected for the study of the fatty acid profile of 'Hass' avocados in the department of Antioquia, Colombia.

Locality	Orchard	Altitude (m a.s.l.)	Latitude (N)	Longitude (W)	Orchard age (years)	Orchard area (ha)	Harvest date
Entrerrios	Guacamayas	2,420	06°33'39.4''	75°32'28.6''	5	5.4	28/07/2011
Rionegro	La Escondida	2,248	06°05'53.0''	75°44'20.0"	5	14	29/09/2011
Jerico	El Encanto	1,900	05°47'48.7"	75°45'45.0"	3	6	06/08/2011
Tamesis	La Maria	1,340	05°41'21.6"	75°42'15.7"	5-6	-	23/08/2011
Venecia	Santa Cruz	1,770	05°55'50.3''	75°46'53.1''	4	20	29/06/2011
	Piedras Blancas	1,510	05°55'58.0''	75°45'33.4''	5	16	23/06/2011

harvest was performed for each orchard according to the practices of the region. The avocado fruits were selected by their physiological maturity stage, identified by the brightness of the fruit skin (dull green), seeking dry matter percentages higher than 21.5% and the absence of physical damage. To study the relationship between the fatty acids and fruit maturity, four fruits in different maturity stages (dry matter content) were taken from one randomly selected tree in the orchards of Entrerrios, Jerico and Tamesis.

Initial fruit physicochemical analysis

For the initial physicochemical characterization of the fruits, the weight of each fruit was determined with a digital scale (Mettler PE 360, Mettler Instruments, Zurich, Switzerland) and the values were recorded in grams. The longitudinal (DL) and equatorial (DE) diameters of each fruit were determined with a digital caliper (resolution 0.01 mm; model 7222, Starrett, Athol, MA). The percentage of dry matter (DM) of each fruit was determined according to the Lee method (Lee, 1981). The samples were dried at 60°C until they reached a constant weight. The weight of each sample was determined after drying and the final and initial weight differences were used to calculate the dry matter percentage. The oil percentage of the dry samples was determined by the method of Latimer (2012) and Lee (1981). A 10 g sample of dry avocado pulp was used to extract the lipids with a Soxhlet for 6-8 h using petroleum ether as the solvent. The oil percentage of the avocado pulp was expressed as a percentage (%, w/w).

Fatty acid profile

The fatty acid profile was studied as a function of the location and fruit maturity stage. A sample of 20 mg was prepared with 1 mL of isopropanol (10 mg mL^{-1}). A solution of fatty acid methyl esters was used as a standard. The analysis was carried out with gas chromatograph Agilent (Wilmington, DE) 7890A and a 30 m capillary column (HP Innowax, Palo Alto, CA) with a flux of 1.0-1.5 mL min^{-1}, tramp temperature of 80 °C for 2 min and a rate of 10°C/min until 280°C (NTC 669 [Incontec, 1989], UNE-EN ISO 5508 [Aenor, 1996], UNE-EN ISO 14103 [Aenor, 2003]). A split-splitless injection system and a FID detector at 280°C were used. Three replicates of each sample were used for the analysis.

Statistical analysis

The results were analyzed with Statgraphics® Centurion XVI v.15.2. The minimal differences between the means were established by ANOVA using the Fisher test with a confidence level of 95%. A simple linear regression model was applied for determining the relationship between the fatty acids and fruit maturity stage (dry matter content). The representativeness of the model was determined at the same level of confidence.

Results and discussion

Table 2 shows the initial physicochemical parameters of the 'Hass' avocado fruit samples from the different orchards at different altitudes.

In this study, the physicochemical parameters were determined only to characterize the initial quality of the fruit sample harvested in each orchard. The orchard with the smallest fruits (115.1 g, 71.4 mm longitudinal diameter and 57.2 mm equatorial diameter) was Tamesis, located at the lowest altitude. There were no significant differences in weight and longitudinal diameter between the other orchards. The fruits of Guacamayas, El Encanto and Santa Cruz had the higher equatorial diameters: 69.5, 69.5 and 70.3 mm, respectively. Cajuste *et al.* (1994) observed a larger fruit size and diameter for higher and medium altitudes in 'Hass' avocados in Mexico. Nevertheless, in our study no direct relationship was found and more evaluations and factors must be taken into account. Additionally, other factors can influence these parameters, such as flowering and harvest season, crop management, environmental parameters and others.

TABLE 2. Physicochemical characterization of the 'Hass' avocado fruit samples at different altitudes in the department of Antioquia, Colombia.

Locality	Orchard	Altitude (m a.s.l.)	Fresh weight (g)	Longitudinal diameter (cm)	Equatorial diameter (cm)	Moisture (%)	Dry matter (%)	Oil (%)
Entrerrios	Guacamayas	2,420	222.5 b	90.1 b	69.5 c	69.3 a	30.7 c	18.9 c
Rionegro	La Escondida	2,248	201.0 b	86.5 b	66.7 bc	71.7 ab	28.3 bc	16.4 bc
Jerico	El Encanto	1,900	216.8 b	91.2 b	69.5 c	73.8 b	26.2 b	14.1 b
Tamesis	La Maria	1,340	115.1 a	71.4 a	57.2 a	69.9 a	30.2 c	17.6 c
Venecia	Santa Cruz	1,770	217.1 b	89.6 b	70.3 c	71.8 ab	28.2 bc	12.9 b
	Piedras Blancas	1,510	200.4 b	90.1 b	65.7 b	81.0 c	19.0 a	7.8 a

Means with different letters in each column indicate significant differences according to the Fisher test ($P \leq 0.05$) ($n=3$).

All of the locations obtained dry matter percentages greater than 21.5% at harvest, except the Piedras Blancas orchard in Venecia, which registered 19.0%. The differences in the dry matter observed between the orchards were due to the difficulty of visually recognizing the physiological maturity stage of fruits in the field, which does not mean that each orchard cannot achieve the same percentage of dry matter in the fruits. According Donetti and Terry (2014), the dry matter increased with maturity, regardless of the growing area.

During fruit ripening, there is an increase in oil content and palatability and a decrease in moisture content (Osuna-García *et al.*, 2010). The percentage of oil in the fruit is directly correlated with the percentage of dry matter, allowing the use of the latter as a maturity index (Lee *et al.*, 1983). Starting in 1925, a minimum standard of 8% oil content in the pulp of avocado fruits was used in the California Avocado Industry in the United States, but, since the eighties, they began using minimum oil content percentages for each cultivar: 10.0% for 'Fuerte' and 11.2% for 'Hass' (Lee *et al.* 1983; Dodd *et al.*, 2010).

As shown in Tab. 2, all of the orchards had an oil percentage higher than 11.2%, except for the Piedras Blancas orchard in Venecia, indicating that the fruit harvested in this orchard did not reach physiological maturity at harvest. The percentages of dry matter and oil were similar to the values reported by Cajuste *et al.* (1994), who registered a 18.9% oil content for 32.2% dry matter in 'Hass' avocados grown in Mexico although the oil content in avocados depends on several factors, such as the cultivar (Orhevba and Jinadu, 2011), agro-ecological conditions of growth (Donetti and Terry, 2014) and the fruit development stage (Villa-Rodríguez *et al.*, 2011).

The obtained fatty acid profile was the same for all of the studied altitudes, but the ratio between certain components changed with the growing area (Tab. 3).

Significant differences were observed at 95% for the oleic, palmitoleic linoleic and linolenic fatty acids were observed. The palmitoleic fatty acid (C16:1) is omega 7 - monounsaturated, oleic (C18:1) is omega 9 - monounsaturated, linoleic (C18:2) is omega 6 - polyunsaturated, and the linolenic (C18:3) is the omega 3 - polyunsaturated. The degree of monounsaturated oil is determined by the amount of oleic acid present in the oil and omegas are crucial for good health. It can be seen in Tab. 3 that the orchards of Rionegro (59.2%) and Entrerrios (55.4%) had the higher percentages of oleic acid, while Piedras Blancas in Venecia (43.2%) and Tamesis (42.1%) had the lower levels of this monounsaturated fatty acid. However, this relationship was reversed for the palmitoleic, linoleic and linolenic acids. The polyunsaturated acids are classified as essential fat acids because the human organism are unable to synthesize them and must be taken in by foods, being this localities of potential interest for health benefits by nutrition because of the higher content of this omegas.

Yanty *et al.* (2011) also found oleic acid as the most dominant fatty acid in 'Hass' avocado cultivars of Australia and Malaysian. However, there were differences between them with regard to the proportional distributions of palmitic and linoleic acids. Donetti and Terry (2012) observed a higher ratio between monounsaturated vs. saturated fatty acids in avocado fruits from South Africa (between 2.7 and 3.0), as compared to fruits from Peru (2.0 and 2.2).

With data from the fatty acid content, an index was calculated from the ratio between each of the fatty acids that were found to be significant at 95% (Tab. 4).

We observed that all of the three indexes showed significant differences between the localities related to the altitude. For the oleic/palmitoleic index, the Rionegro locality had the highest value, followed by Entrerrios, Jerico, Venecia and, finally, Tamesis. For the oleic/linoleic ratio, the same trend was also observed and, for the Linoleic/Palmitoleic

TABLE 3. Fatty acid content of 'Hass' avocado fruits at different altitudes in the department of Antioquia, Colombia.

Locality	Orchard	Altitude (m a.s.l.)	Fatty acid (%)								
			Myristic (C14: 0)	Palmitic (C16: 0)	Palmitoleic (C16: 1)	Stearic (C18: 0)	Oleic (C18: 1)	Linoleic (C18: 2)	Linolenic (C18: 3)	Eicosanoic (C20: 0)	Eicosenoic (C20: 1)
Entrerrios	Guacamayas	2,420	0.04 a	18.14 a	10.84 b	1.52 bc	55.38 c	13.80 b	1.16 a	0.15 a	0.46 b
Rionegro	La Escondida	2,248	0.15 c	18.21 a	8.45 a	0.99 a	59.19 c	11.60 a	0.99 a	0.15 a	0.27 a
Jerico	El Encanto	1,900	0.10 b	19.63 ab	13.19 c	1.38 b	50.63 b	13.28 ab	1.08 a	0.17 ab	0.55 bc
Tamesis	La Maria	1,340	0.15 c	21.45 b	17.05 e	1.91 d	42.14 a	15.14 c	1.53 b	0.19 ab	0.49 b
Venecia	Santa Cruz	1,770	0.14 c	20.27 b	15.83 d	1.67 c	46.76 ab	13.29 ab	1.18 a	0.21 b	0.65 c
	Piedras Blancas	1,510	0.17 c	20.54 b	15.56 d	1.62 c	43.23 a	16.58 c	1.62 b	0.18 ab	0.50 b

Means with different letters in each column indicate significant differences according to the Fisher test ($P \leq 0.05$) ($n=3$).

TABLE 4. Fatty acids index in 'Hass' avocado fruits at different altitudes in the department of Antioquia of Colombia.

Locality	Orchard	Altitude (m a.s.l.)	Index of fatty acid		
			Oleic/palmitoleic	Linoleic/palmitoleic	Oleic/linoleic
Entrerrios	Guacamayas	2,420	5.13 c	1.28 b	4.07 c
Rionegro	La Escondida	2,248	7.00 d	1.37 b	5.10 d
Jerico	El Encanto	1,900	4.22 b	1.01 a	3.81 bc
Tamesis	La Maria	1,340	2.48 a	0.89 a	2.78 a
Venecia	Santa Cruz	1,770	2.95 a	0.84 a	3.52 b
	Piedras Blancas	1,510	2.78 a	1.07 a	2.78 a

Means with different letters in each column indicate significant differences according to the Fisher test ($P \leq 0.05$) ($n=3$).

index, two groups were significantly differentiated in the relationship with the altitude: Entrerrios and Rionegro (> 2,000 m a.s.l.) had the higher ones and Jerico, Venecia and Tamesis (< 2,000 m a.s.l.) had the lower ones.

The study of the relationship between the fatty acid content and regions is interesting because, due to its importance to human health, it may be consider as a variable in future studies for PDO or protected geographical indication (PGI), as it shows a close relationship with the geographical growing area. Donetti and Terry (2014), studying biochemical markers for defining the growing area and ripening stage of imported 'Hass' avocado fruits, found that the oleic acid content can be used to distinguish between avocado fruit growing areas. The oil composition differed according to origin and harvest-time. Chilean fruits had a higher oleic content (57-61%), followed by Spanish (54-60%) and Peruvian (40-47%) fruits. Landahl *et al.* (2009) found that the composition of fatty acids, oil and dry matter contents in 'Hass' avocados varied significantly according to origin. Additionally, the avocado's many nutrients and phytochemicals may support a wide range of potential health benefits (USDA, 2011). According to the USDA and HHS (2010), the health benefits of avocado fruits rich in monounsaturated fatty acids can be part of a heart healthy dietary pattern, such as the DASH diet plan. Avocado fruit has been shown to have similar effects on weight control as low-fat fruits and vegetables (Bes-Rastrollo *et al.*, 2008) and have a similar composition profile to that of tree nuts, which have a heart health claim, with less than half the calories (FDA, 2004). This type of certification could add economical advantages for the export market and beneficiate domestic consumers of 'Hass' avocados.

The fatty acid profile and content was also studied at different stages of maturity (dry matter content) for 'Hass' avocado fruits in three localities. The evolution of this parameter is shown in Tab. 5.

We observed that the palmitic acid significantly decreased with increasing fruit maturity stages (23.8-16.9%) in Entrerrios, while the oleic acid increased slightly with the maturity (56.5-59.1%), but without significant changes. For the other locations, no significant changes were observed for these components. The palmitoleic acid increased significantly with the maturity stage for all of the locations and the linoleic slightly decreased with maturation for Jerico.

TABLE 5. Relationship between fatty acids content and maturity index (dry matter, %) in cv. Hass avocado at different altitudes in the department of Antioquia, Colombia.

Locality	Orchard	Maturity index (dry matter, %)	Fatty acid (%)								
			Myristic (C14:0)	Palmitic (C16:0)	Palmitoleic (C16:1)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Linolenic (C18:3)	Eicosanoic (C20:0)	Eicosenoic (C20:1)
Entrerrios	Guacamayas 2,420 m a.s.l.	14.0	0.57 b	23.83 c	6.21 a	2.70 b	56.48 a	8.70 a	0.89 a	0.19 a	0.43 a
		20.9	0.17 a	20.68 b	6.57 a	1.26 a	57.09 a	12.38 c	1.32 b	0.15 a	0.30 a
		25.8	0.07 a	19.12 b	6.26 a	1.11 a	58.66 a	12.68 c	1.44 b	0.10 a	0.55 b
		31.9	0.08 a	16.85 a	9.62 b	1.25 a	59.11 a	11.32 b	1.20 b	0.12 a	0.44 a
Jerico	El Encanto 1,900 m a.s.l.	17.0	0.16 a	21.49 b	10.54 a	1.10 a	48.89 a	17.30 b	0.20 a	0.10 a	0.21 a
		19.5	0.13 a	20.09 ab	11.34 a	1.03 a	49.14 a	14.68 a	1.38 b	0.16 a	0.23 a
		23.6	0.13 a	18.75 a	13.17 b	1.14 a	51.36 a	15.52 a	1.33 b	0.15 a	0.28 a
		32.6	0.10 a	18.78 a	14.26 b	0.94 a	48.80 a	15.61 a	1.12 b	0.11 a	0.29 a
Tamesis	La Maria 1,340 m a.s.l.	13.0	0.15 a	22.13 a	13.38 a	1.35 a	42.60 a	18.32 a	1.57 b	0.17 a	0.34 a
		28.6	0.20 a	22.16 a	14.36 ab	1.41 a	43.25 a	16.79 a	1.38 a	0.16 a	0.30 a
		30.7	0.15 a	22.85 a	14.97 b	1.17 a	42.16 a	16.69 a	1.57 b	0.18 a	0.26 a
		32.4	0.27 a	21.28 a	17.09 c	1.29 a	40.16 a	17.70 a	1.26 a	0.19 a	0.79 b

Means with different letters in each column indicate significant differences according to the Fisher test ($P \leq 0.05$) ($n=3$).

These changes in the fatty acid composition as related to the fruit maturity could have been due to the metabolism of these acids during fruit respiration in the trees (Meigh and Hulme, 1965). On the other hand, geographical and environmental factors can influence the fruit respiration behavior in trees, reflecting differences between the orchards.

Ozdemir and Topuz (2004) studied changes in dry matter content, oil content and fatty acid composition in 'Hass' and 'Fuerte' avocados during the harvest and post-harvest periods, noting that, while oleic acid increased significantly with a late harvest, other fatty acids decreased. In particular, the palmitic acid decreased 46.5% between November and January. Villa-Rodríguez *et al.* (2011) also reported oleic acid as the main fatty acid (about 67-70% of the total content) in 'Hass' avocados, observing a significant increase in monounsaturated and saturated fatty acids during avocado ripening, while the polyunsaturated fatty acid content decreased. Lu *et al.* (2009) stated that, as the avocado ripens, the saturated fat decreases and the monounsaturated oleic acid increases. Landahl *et al.* (2009) and Pedreschi *et al.* (2014) observed that linoleic acid was differentially accumulated in 'Hass' avocado fruits during ripening.

The relationship between the avocado fruit maturity stage and the content of monounsaturated versus saturated fatty acids is an important factor to consider at harvest time, especially if the target is the health food market. Since avocado fruits are a farm-to-market food because they do not require processing, preservatives or taste enhancers, every effort must be made to achieve the highest quality and health parameters at harvest to secure health claims and value added certifications.

Table 6 shows the results of fitting a linear model to describe the relationship between the content of fatty acids and / or fatty acid ratio and the fruit maturity stage (dry matter content) for the locations that showed good correlation coefficients.

Some fatty acids showed a linear relationship with the fruit maturity stage, varying the type of acid or index with the location. The Entrerrios orchard, at the highest altitude, was the one with the most acids and indexes correlated with the maturation stage (dry matter), while the Tamesis orchard only showed a negative correlation for the linoleic/palmitoleic index, showing that the orchard altitude significantly affected the fatty acid metabolism of the avocado fruits. In the Entrerrios orchard, a high linear correlation was presented with the maturity fruit stage for the oleic acid (positive) and palmitic acid (negative).

The models showed a strong relationship between the variables for the three locations, verifying a statistically significant relationship between the two parameters (fatty acid and fatty acid index) and the fruit maturity stages with a confidence level of 95.0%. These models are a useful tool because they allow for an easy determination of the fatty acids as geographical and health quality markers through the analysis of the dry matter percentage.

Conclusions

According to the results, oleic acid had the highest percentage of fatty acid in the 'Hass' avocados for all of the studied orchards and this percentage decreased dramatically at the lower altitudes, meanwhile the percentage of palmitoleic

TABLE 6. Linear regression between the fatty acids and fruit maturity stage (dry matter content) for cv. 'Hass' avocados at different altitudes in the Antioquia Province of Colombia.

Locality/orchard/altitude	Fatty acid (FA) or fatty acid index (FAI)	Equation	Correlation coefficient
Entrerrios, Guacamayas 2,420 m a.s.l.	Oleic	FA (%) = 54.2 + [0.2 * DM (%)]	0.93
	Palmitic	FA (%) = 29.0 - [0.4 * DM (%)]	0.99
	Palmitic/palmitoleic	FAI = 5.5 - [0.1 * DM (%)]	0.90
	Oleic/palmitic	FAI = 1.5 + [0.1 *DM (%)]	0.99
	Palmitoleic/stearic	FAI = - 1.4 + [0.3 *DM (%)]	0.96
	Palmitoleic/eicosanoic	FAI = - 6.8 + [2.7 * DM (%)]	0.97
	Palmitoleic/myristic	FAI = - 84.9 + [6.5 *DM (%)]	0.97
	Eicosanoic/myristic	FAI = - 0.6 + [0.1 * DM (%)]	0.94
	Eicosanoic/palmitoleic	FAI = 0.04 - [0.01 * DM (%)]	0.97
Jerico, El Encanto 1,900 m a.s.l.	Stearic/eicosenoic	FAI = 7.1 - [0.1 * DM (%)]	0.91
	Oleic/myristic	FAI = 141.8 + [10.7 * DM (%)]	0.93
	Linoleic/myristic	FAI = 50.3 + [3.2 * DM (%)]	0.97
	Eicosenoic/stearic	FAI = 0.07 + [0.01 * DM (%)]	0.98
	Eicosenoic/myristic	FAI = - 0.3 + [0.1 * DM (%)]	0.97

and linoleic increased in these orchards. The oleic/palmitoleic, linoleic/palmitoleic and oleic/linoleic indexes showed significant differences between the altitudes. The fatty acid content, due to its importance for human health and the close relationship observed with the geographical area, is a variable to consider in future studies for protected designation of origin (PDO) certifications. The palmitoleic acid increased significantly with the fruit maturity stage (dry matter content) for all of the studied locations. Some fatty acids showed a high linear correlation with the fruit maturity stage, varying the type of acid or index with altitude. This is the first study reported for 'Hass' avocado fatty acid contents in the department of Antioquia, Colombia. Nevertheless, we recommend continuing with evaluations over the course of years and harvests, with more contrasting environments, in order to obtain more information about fatty acids as health and geographical markers. Also, studies on antioxidant activity and bioavailability must be taken in account for each orchard and harvest time to show the relationship between oleic acid and human health.

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